DOWN ON THE FARM

NANOTECHNOLOGY IN THE FOOD CHAIN

Nanotechnology has profound implications for food sovereignty worldwide and may be the technology that can be adapted for surveillance, social control and biowarfare.

Part 1 of 2

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ETC Group
431 Gilmour St, Second Floor,
Ottawa, ON, Canada K2P 0R5
Tel: +1 613-241-2267
Fax: +1 613-241-2506
www.etcgroup.org etc@etcgroup.org

The Impact of Nano-Scale Technologies on Food and Agriculture

SUMMARY

Nanotechnology, the manipulation of matter at the scale of atoms and molecules (a nanometre [nm] is one-billionth of a metre [or 10^{-9}m]), is rapidly converging with biotech and information technology to radically change food and agricultural systems.

Over the next two decades, the impacts of nano-scale convergence on farmers and food will exceed that of farm mechanisation or of the Green Revolution. Converging technologies could reinvigorate the battered agrochemical and agbiotech industries, igniting a still more intense debate—this time over "atomically-modified" foods. No government has developed a regulatory regime that addresses the nano-scale or the societal impacts of the invisibly small. A handful of food and nutrition products containing invisible, unlabelled and unregulated nano-scale additives are already commercially available. Likewise, a number of pesticides formulated at the nano-scale are on the market and have been released in the environment.

From soil to supper, nanotechnology will not only change how every step of the food-chain operates but it will also change who is involved. At stake is the world's $3 trillion food retail market, agricultural export markets valued at $544 billion, the livelihoods of some 2.6 billion farming people and the well-being of the rest of us who depend upon farmers for our daily bread.[1]

Nanotech has profound implications for farmers (and fisher people and pastoralists) and for food sovereignty worldwide. Agriculture may also be the proving ground for technologies that can be adapted for surveillance, social control and biowarfare.

The GM (genetically modified) food debate not only failed to address environmental and health concerns, it disastrously overlooked the ownership and control issues. How society will be affected and who will benefit are critical concerns.

Because nanotech involves all matter, nano-patents can have profound impacts on the entire food system and all sectors of the economy. Synthetic biology and nano-materials will dramatically transform the demand for agricultural raw materials required by processors. Nano-products came to market—and more are coming—in the absence of regulation and societal debate. The merger of nanotech and biotech has unknown consequences for health, biodiversity and the environment.

Governments and opinion-makers are running 8-10 years behind society's need for information, public debate and policies.

INTRODUCTION—THE LAY OF THE LAND

Size Matters

The nano-scale moves matter out of the realm of conventional chemistry and physics into "quantum mechanics"—imparting unique characteristics to traditional materials—and unique health and safety risks. With only a reduction in size (to under 100 nm) and no change in substance, a material's properties can change dramatically.

Characteristics—such as electrical conductivity, reactivity, strength, colour and especially importantly, toxicity—can all change in ways that are not easily predicted. For example, a substance that is red when it is a meter wide may be green when its width is only a few nanometres; carbon in the form of graphite is soft and malleable; at the nano-scale, carbon can be stronger than steel.

A single gram of catalyst material that is made of 10-nanometre particles is about 100 times more reactive than the same amount of the same material made of one-micrometre sized particles (a micron is 1,000 times bigger than a nanometre). Aside from the serious toxicity implications of quantum property changes, it is not always necessary or useful to draw a distinct line between nano-scale and microscale applications: "nano-scale" is not necessarily the goal in every case; "micro-scale" may be adequate for some purposes—and for others both nano-scale and micro-scale devices, materials or particles may serve equally well. Both may prove disruptive.

Keeping Nanoparticles Out of the Environment

Applying nanoparticles in agriculture raises environmental and health concerns since nanoparticles appear to demonstrate a different toxicity than larger versions of the same compound. In 2003, Dr Vyvyan Howard, founding editor of the *Journal of Nanotoxicology*, undertook a review of scientific literature on nanoparticle toxicity for ETC Group. Dr Howard concluded that nanoparticles as a class appear to be more toxic as a result of their smaller size, also noting that nanoparticles could move more easily into the body, across protective membranes such as skin, the blood-brain barrier or perhaps the placenta.

A study published by Dr Eva Oberdörster in July 2004 found that large mouth bass (fish) exposed to small amounts of buckyballs (manufactured nanoparticles of 60 carbon atoms) resulted in rapid onset of damage in the brain, the death of half the water fleas living in the water in which the fish lived.[14] Other studies show that nanoparticles can move in unexpected ways through soil potentially carry other substances with them. Given the knowledge gaps, many expert commentators are recommending that release of engineered nanoparticles be minimised or prohibited in the environment.

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NANO-AGRICULTURE: DOWN ON THE FARM

In December 2002, the United States Department of Agriculture (USDA) drafted the world's first "roadmap" for applying nanotechnology to agriculture and food.[16] A wide collection of policy makers, land-grant university representatives and corporate scientists met at Cornell University (New York, USA) to share their vision of how to remake agriculture using nano-scale technologies.

Agriculture, according to the new nano-vision, needs to be more uniform, further automated, industrialised and reduced to simple functions. In our molecular future, the farm will be a wide-area biofactory that can be monitored and managed from a laptop and food will be crafted from designer substances delivering nutrients efficiently to the body.

Nanobiotechnology will increase agriculture's potential to harvest feedstocks for industrial processes. Meanwhile tropical agricultural commodities such as rubber, cocoa, coffee and cotton—and the small-scale farmers who grow them—will find themselves quaint and irrelevant in a new nanoeconomy of "flexible matter" in which the properties of industrial nanoparticles can be adjusted to create cheaper, "smarter" replacements.

Just as GM agriculture led to new levels of corporate concentration all along the food chain, so proprietary nanotechnology, deployed from seed to stomach, genome to gullet, will strengthen the grasp of agribusiness over global food and farming at every stage—all, ostensibly, to feed the hungry, safeguard the environment and provide consumers with more choice.

For two generations, scientists have manipulated food and agriculture at the molecular level. Agro-Nano connects the dots in the industrial food chain and goes one step further down. With new nano-scale techniques of mixing and harnessing genes, genetically modified plants become atomically modified plants. Pesticides can be more precisely packaged to knock-out unwanted pests and artificial flavourings and natural nutrients engineered to please the palate. Visions of an automated, centrally-controlled industrial agriculture can now be implemented using molecular sensors, molecular delivery systems and low-cost labour.

Downsized Seeds

Re-organising natural processes is hardly a new idea. To increase yields during the Green Revolution, Northern scientists bred semi-dwarf plants that were better able to absorb synthetic fertilisers and by doing so, increased the plants' need for pesticides. To further the dependency, the agricultural biotechnology industry designed plants that could tolerate toxic chemicals. Agbiotech companies had a choice: they could have structured new chemicals to meet the needs of the plants or they could have manipulated plants to meet the needs of company herbicides.

They opted to preserve their herbicides. Now nanotech companies are going down the same path—looking for new ways that life and matter can serve the needs of industry.

Gene therapy for plants

Researchers are developing new techniques that use nanoparticles for smuggling foreign DNA into cells. For example, at Oak Ridge National Laboratory—the US Department of Energy lab that played a major role in the production of enriched uranium for the Manhattan Project—researchers have hit upon a nano-technique for injecting DNA into millions of cells at once. Millions of carbon nanofibres are grown sticking out of a silicon chip with strands of synthetic DNA attached to the nanofibres.[17] Living cells are then thrown against and pierced by the fibres, injecting the DNA into the cells in the process:

"It's like throwing a bunch of baseballs against a bed of nails... We literally throw the cells onto the fibers, and then smush the cells into the chip to further poke the fibers into the cell." —Timothy McKnight, Engineer, Oak Ridge Laboratory.[18]

Once injected, the synthetic DNA expresses new proteins and new traits.

Oak Ridge has entered into collaboration with the Institute of Paper Science and Technology in a project aimed to use this technique for genetic manipulation of loblolly pine, the primary source of pulpwood for the paper industry in the USA.

Unlike existing genetic engineering methods, the technique developed by Oak Ridge scientists does not pass modified traits on to further generations because, in theory, the DNA remains attached to the carbon nanofibre, unable to integrate into the plants' own genome. The implication is that it would be possible to reprogram cells for one time only. According to Oak Ridge scientists, this relieves concerns about gene flow associated with genetically modified plants, where genes are transferred between unrelated organisms or are removed or rearranged within a species. If the new technique enables researchers to selectively switch on or off a key trait such as fertility, will seed corporations use the tiny terminators to prevent farmers from saving and re-using harvested seed—compelling them to return to the commercial seed market every year to obtain the activated genetic trait they need?

This approach also raises a number of safety questions: what if the nanofibres were ingested by wildlife or humans as food? What are the ecological impacts if the nanofibres enter the cells of other organisms and cause them to express new proteins? Where will the nanofibres go when the plant decomposes in the soil? Carbon nanofibres have been compared to asbestos fibres because they have similar shapes. Initial toxicity studies on some carbon nanofibres have demonstrated inflammation of cells. A study by NASA found inflammation in the lungs to be more severe than in cases of silicosis,[19] though Nobel laureate Richard Smalley, Chairman of Carbon Nanotechnologies Inc. gives little weight to these concerns: "We are confident there will prove out to be no health hazards but this [toxicology] work continues."[20]

... atom-scale technologies will further concentrate economic power in the hands of giant multinational corporations.

Atomically Modified Seeds

In March 2004, ETC Group reported on a nanotech research initiative in Thailand that aims to atomically modify the characteristics of local rice varieties.[21] In a three-year project at Chiang Mai University's nuclear physics laboratory, researchers "drilled" a hole through the membrane of a rice cell in order to insert a nitrogen atom that would stimulate the rearrangement of the rice's DNA.[22] So far, researchers have been able to alter the colour of a local rice variety from purple to green. In a telephone interview, Dr Thirapat Vilaithong, director of Chiang Mai's Fast Neutron Research Facility, told Biodiversity Action Thailand (BIOTHAI) that their next target is Thailand's famous jasmine rice.[23] The goal of their research is to develop jasmine varieties that can be grown all year long, with shorter stems and improved grain colour.[24]

One of the attractions of this nano-scale technique, according to Dr Vilaithong, is that, like the Oak Ridge project, it does not require the controversial technique of genetic modification. "At least we can avoid it," Dr Vilaithong said.[25] Civil society organisations in Thailand are sceptical of the benefits.

Nanocides: Pesticides via Encapsulation

Pesticides containing nano-scale active ingredients are already on the market, and many of the world's leading agrochemical firms are conducting R&D on the development of new nano-scale formulations of pesticides.

A more sophisticated approach to formulating nano-scale pesticides involves encapsulation—packaging the nano-scale active ingredient within a kind of tiny "envelope" or "shell." Both food ingredients and agrochemicals in microencapsulated form have been on the market for several decades. According to industry, the reformulation of pesticides in microcapsules has triggered "revolutionary changes," including the ability to control under what conditions the active ingredient is released.

According to the agrochemical industry, re-formulating pesticides in microcapsules can also extend patent protection, increase solubility, reduce the contact of active ingredients with agricultural workers[36] and may have environmental advantages such as reducing run-off rates.

Concerns raised by encapsulation

• Both biological activity and environmental/worker exposure can be longer-lasting; beneficial insects and soil life may be affected.

• Could nano-scale pesticides be taken up by plants and smuggled into the food chain?

• Pesticides can be more easily aerosolised as a powder or droplets—therefore able to be inhaled and perhaps a greater threat to human health and safety.

• Could pesticides formulated as nanocapsules or nano-scale droplets exhibit different toxicity and enter the body and affect wildlife through new exposure routes, for example, across skin?

• Potential for use as a bioweapons delivery vehicle.

• What other external triggers might affect the release of the active ingredient (e.g., chemical binding, heat or break down of the capsule)?

• Microcapsules are similar in size to pollen and may poison bees and/or be taken back to the hives and incorporated in honey. Because of their size, "microencapsulated insecticides are considered more toxic to honey bees than any formulation so far developed."[55] Will nanocapsules be more lethal?

• It is not known how 'unexploded' nanocapsules will behave in the human gut if ingested with food.

Implications for Nanobioweaponry

Nanocapsules and microcapsules make an ideal vehicle for delivering chemical and biological weapons because they can carry substances intended to harm humans as easily as they can carry substances intended to kill weeds and pests. By virtue of their small size, DNA nanocapsules may be able to enter the body undetected by the immune system and then become activated by the cells' own mechanisms to produce toxic compounds. The increased bioavailability and stability of nano-encapsulated substances in the environment may offer advantages to the Gene Giants, but the same features could make them extremely potent vehicles for biological warfare. In addition, because of their increased bioavailability only a small quantity of the chemical is needed.

Nanocapsules and microcapsules make an ideal vehicle for delivering chemical and biological weapons...

When programmed for external triggers such as ultrasound or magnetic frequencies, activation can be controlled remotely, suggesting a number of grim scenarios. Could agrochemical/seed corporations remotely activate triggers to cause crop failure if the farmer infringes the company's patent or fails to follow prescribed production practices?

What if nanocapsules containing a potent compound are added to a regional water supply by a foreign aggressor or terrorist group?

According to The Sunshine Project, the "Australia Group" (a group of 24 industrialised nations) recently proposed that microencapsulation technologies be added to a common list of technologies banned from export to 'untrustworthy' governments for fear of use as bioweapons.[57] Documents obtained by Sunshine Project also show that the US military funded the University of New Hampshire in 1999-2000 to develop microcapsules containing corrosive and anaesthetic (that is, to produce unconsciousness) chemicals.

When programmed for external triggers such as ultrasound or magnetic frequencies, activation can be controlled remotely...

The documents describe how the microcapsules could be fired at a crowd, corrode protective gear and then break open in contact with the moisture on human skin.[58]

From Smart Dust to Smart Fields

"Precision farming," also known as site-specific management, describes a bundle of new information technologies applied to the management of large-scale, commercial agriculture. Precision farming technologies include, for example: personal computers, satellite-positioning systems, geographic information systems, automated machine guidance, remote sensing devices and telecommunications.

"Smart Dust" and "Ambient Intelligence"

The idea that thousands of tiny sensors could be scattered like invisible eyes, ears and noses across farm fields and battlefields sounds like science fiction. But ten years ago, Kris Pister, a professor of Robotics at University of California, Berkeley secured funding from the US Defense Advanced Research Project Agency (DARPA) to develop autonomous sensors that would each be the size of a match head.

Using silicon-etching technology, these motes ("smart dust" sensors) would feature an onboard power supply, computation abilities and the ability to detect and then communicate with other motes in the vicinity. In this way the individual motes would self-organise into ad hoc computer networks capable of relaying data using wireless (i.e., radio) technology.

DARPA's immediate interest in the project was to deploy smart dust networks over enemy terrain to feed back real time news about troop movements, chemical weapons, and other battlefield conditions without having to risk soldiers' lives.

However, like that other groundbreaking DARPA project, the Internet, it swiftly became clear that tiny surveillance systems would have endless civilian uses, from monitoring energy-use in office buildings to tracking goods through a supply chain, to environmental data monitoring.

Today, wireless micro and nanosensors like the ones pioneered by Kris Pister are an area of intense research for large corporations from Intel to Hitachi, a focus of development at all US national defence laboratories, and in fields as wide apart as medicine, energy and communications. Touted by *The Economist*, *Red Herring* and *Technology Review* as the 'next big thing', ubiquitous wireless sensors embedded in everything from the clothes we wear to the landscapes we move through could fundamentally alter the way we relate to everyday goods, services, the environment and the State.

The aim is to develop what researches call 'ambient intelligence'—smart environments that use sensors and artificial intelligence to predict the needs of individuals and respond accordingly: offices that adjust light and heating levels throughout the day or clothes that alter their colours or warmth depending on the external environment.

A simple example of ambient intelligence already in use is an airbag system in newer cars, which "senses" an imminent crash and deploys a pillow to soften the blow to the driver.

Kris Pister's dust motes are currently far from nano (they are roughly coin-sized), but they have already been licensed to commercial companies. In 2003 Pister established a "smart dust" spin-off company, Dust, Inc. For a light taster of a society steeped in ambient intelligence, Kris Pister makes the following speculations:[67]

• "In 2010 a speck of dust on each of your fingernails will continuously transmit fingertip motion to your computer. Your computer will understand when you type, point, click, gesture, sculpt, or play air guitar.

• "In 2010 infants will not die of SIDS [Sudden Infant Death Syndrome], or suffocate, or drown, without an alert being sent to the parents. How will society change when your neighbors [sic] pool calls your cell phone to tell you that Johnny is drowning and you're the closest adult that could be located?

• "In 2020 there will be no unanticipated illness. Chronic sensor implants will monitor all of the major circulator systems in the human body, and provide you with early warning of an impending flu, or save your life by catching cancer early enough that it can be completely removed surgically."

Nanosensors

With ongoing technical advances, microsensors are shrinking in size and their sensor capabilities are expanding. Market analysts predict that the wireless sensor market will be worth $7 billion by 2010.[68]

Nanosensors made out of carbon nanotubes or nano-cantilevers (balanced weighing devices) are small enough to trap and measure individual proteins or even molecules. Nanoparticles or nanosurfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria.

Other nanosensors work by triggering an enzyme reaction or by using nano-engineered branching molecules called dendrimers as probes to bind to target chemicals and proteins.

Not surprisingly, a great deal of government-funded research in nanosensors aims to detect minute quantities of biowarfare agents such as anthrax or chemical toxins to counter terrorist attacks on US soil as well as to warn soldiers on a battlefield of possible risks.

For example, the US government's "SensorNet" project attempts to cast a net of sensors across the entire United States that will act as an early warning system for chemical, biological, radiological, nuclear and explosive threats.[69]

The SensorNet will integrate nano-, micro- and conventional sensors into a single nationwide network that will feed back to an existing US network of 30,000 mobile phone masts, forming the skeleton of an unparalleled national surveillance network. Oak Ridge National Laboratory is now field-testing SensorNet. US government defence laboratories such as Los Alamos and Sandia are developing the nanosensors themselves.

Sizing up Sensors

Sensor technology could benefit large-scale, highly industrialised farms that are already adopting GPS tractors and other precision farming techniques. Ultimately, sensors are likely to increase productivity, drive down farm prices, reduce labour and win a small advantage in the global marketplace for the largest industrial farm operators.

It is not small-scale farmers who will benefit from ubiquitous sensor networks, but the giant grain traders such as Cargill and ADM, who are positioned to aggregate data from several thousand farms in order to determine which crops are grown, by whom and what price will be paid, depending on market demand and global prices.

Sensors will marginalise farmers' most unique assets—their intimate local knowledge of place, climate, soils, seeds, crops and culture. In a wirelessly monitored world all of this is reduced to real-time raw data, interpreted and leveraged remotely.

Why employ smart farmers when sensors and computers can make 'smart farms' operate without them?

NanoSurveillance

Agricultural sensor networks may also be pressed into use as civil surveillance systems in the interest of 'homeland security'. Wireless sensor networks—whether in agriculture or any other application—threaten to stifle dissent and invade privacy. Michael Mehta, a sociologist at the University of Saskatchewan (Canada), believes that the environment equipped with multiple sensors could destroy the notion of privacy altogether—creating a phenomenon that he calls "nanopanopticism" (i.e., all seeing) in which citizens feel constantly under surveillance.[77]

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In a recent report, the UK Royal Society also highlighted privacy concerns raised by nanosensors:

"…[Sensor] *devices might be used in ways that limit individual or group privacy by covert surveillance, by collecting and distributing personal information (such as health or genetic profiles) without adequate consent, and by concentrating information in the hands of those with the resources to develop and control such networks.*"

—Royal Society, "Nanoscience and nanotechnologies: opportunities and uncertainties"[78]

Particle Farming

In the future, industrial nanoparticles may not be produced in a laboratory, but grown in fields of genetically engineered crops—what might be called "particle farming".

It's been known for some time that plants can use their roots to extract nutrients and minerals from the soil but research from the University of Texas-El Paso confirms that plants can also soak up nanoparticles that could be industrially harvested.

In one particle-farming experiment, alfalfa plants were grown on an artificially gold-rich soil on university grounds. When researchers examined the plants, they found gold nanoparticles in the roots and along the entire shoot of the plants that had physical properties like those produced using conventional chemistry techniques, which are expensive and harmful to the environment.[106]

The metals are extracted simply by dissolving the organic material.

Initial experiments showed that the gold particles formed in random shapes, but changing the acidity of the growing medium appears to result in more uniform shapes.[107]

The researchers are now working with other metals and with wheat and oats in addition to alfalfa to produce nanoparticles of silver, Europium, palladium, platinum and iron.[108]

For industrial-scale production, the researchers speculate that the particle plants can be grown indoors in gold-enriched soils, or they can be farmed nearby abandoned gold mines.[109]

Nanomal Pharm

Livestock and fish will also be affected by the nanotechnology revolution. While the great hopes of nanomedicine are disease detection and new pharmaceuticals for humans, veterinary applications of nanotechnology may become the proving ground for untried and more controversial techniques—from nanocapsule vaccines to sex selection in breeding.

Biochips

Using biochips, biological samples such as blood, tissue and semen can be instantaneously analysed and manipulated. In fewer than five years, biochips have become a standard technology for genomics and drug discovery, and they are now moving into commercial healthcare and food safety applications.

A biochip (or microarray) is a device typically made of hundreds or thousands of short strands of artificial DNA deposited precisely on a silicon circuit. In DNA arrays, each DNA strand acts as a selective probe and when it binds to material in a sample (e.g., blood) an electrical signal is recorded. Rather like conducting a word search across a piece of text, the biochip is able to report back on found genetic sequences based on the DNA probes built into it.

The best-known biochips are those produced by Affymetrix, the company that pioneered the technology and was first to produce a DNA chip that analyses an entire human genome on a single chip the size of a dime.[116]

In addition to DNA biochips there are other variations that detect minute quantities of proteins and chemicals in a sample, making them useful for detecting biowarfare agents or disease.

Biochip analysis machines the size of an inkjet printer are commercially available from companies such as Agilent (Hewlett-Packard) and Motorola—each able to process up to 50 samples in around half an hour.

Nano-Veterinary Medicine

The field of nanomedicine offers ever more breathless promises of new diagnoses and cures as well as ways of improving human performance. The US National Science Foundation expects nanotechnology to account for around half of all pharmaceutical industry sales by 2010. What is less hyped is that the same impact is likely to hit the animal health market—either as nanotechnologies show their worth in human medicine or as a proving ground for more controversial approaches to nanomedicine, such as using DNA nanocapsules. Companies such as SkyePharma, IDEXX and Probiomed are currently developing nanoparticle veterinary applications. A full assessment of how pharmaceutical companies are using nanotechnology in drug development and delivery is beyond the scope of this report. Briefly summarised below are some of the key technologies that are also relevant to animal pharmaceuticals:

Drug Discovery

The ability to image and isolate biological molecules on the nano-scale opens the door for more precise drug design as well as much faster genomic screening and screening of compounds to assess their suitability as drugs. Pharma companies are particularly interested in using biochips and microfluidic devices to screen tissues for genetic differences so that they can design genetically targeted drugs (pharmacogenomics).[122]

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Disease Detection

Nanoparticles, which are able to move easily around the body, can be used for diagnosis. Of particular interest are quantum dots—cadmium selenide nanocrystals which fluoresce in different colours depending on their size. Quantum dots can be functionalised to tag different biological components, like proteins or DNA strands, with specific colours. In this way a blood sample can be quickly screened for certain proteins that may indicate a higher propensity for disease.

New Delivery Mechanisms

Drugs themselves are set to shrink. Nano-sized structures have the advantage of being able to sneak past the immune system and across barriers (e.g., the blood-brain barrier or the stomach wall) the body uses to keep out unwanted substances.

Pharmaceutical compounds reformulated as nanoparticles not only reach parts of the body that today's formulations cannot, their large surface area can also make them more biologically active.

Increased bioavailability means that lower concentrations of expensive drug compounds would be required, with potentially fewer side effects.[124] Nanoparticles can also be used as carriers to smuggle attached compounds through the body.

Leading nanopharma companies such as SkyePharma and Powderject (now a wholly owned subsidiary of Chiron) have developed methods of delivering nanoparticle pharmaceuticals across skin or via inhalation. Researchers in Florida are working on nano-delivery systems that diffuse drugs across the eye from specially impregnated contact lenses. As with pesticide delivery, the big interest is in 'controlled release.'

Many of the big pharma and animal pharma companies working on nanodrugs are using encapsulation technologies such as nanocapsules to smuggle active compounds into and around the body. The capsules can be functionalised to bind at specific places in the body, or be activated by an external trigger, such as a magnetic pulse or ultrasound. The USDA compares these functionalised drug nanocapsules, called "Smart Delivery Systems," to the postal system, where molecular-coded "address labels" ensure that the packaged pharmaceutical reaches its intended destination.[125]

Besides capsules, other nanomaterials being used to deliver drugs include:

• **BioSilicon**—a highly porous silicon-based nanomaterial product, which can release a medicine slowly over a period of time. Developed by Australian company pSivida, the company uses its BioSilicon technology to fashion tiny capsules (to be swallowed) and also tiny needles that can be built into a patch to invisibly pierce the skin and deliver drugs.[126]

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• **Fullerenes**, the so called "miracle molecules" of nanotechnology (buckyballs and carbon nanotubes are included in this class of carbon molecules), are hollow cages of sixty carbon atoms less than a couple of nanometres wide.

Because they are hollow, pharma companies are exploring filling the fullerenes with drug compounds and then functionalising them to bind in different parts of the body.

• **Dendrimers** are branching molecules that have a tree-like structure and are becoming one of the most popular tools in nanotechnology. Because of their shape and nano-size, dendrimers have three advantages in drug delivery: first, they can hold a drug's molecules in their structure and serve as a delivery vehicle; second, they can enter cells easily and release drugs on target; third, and most importantly, dendrimers don't trigger immune system responses.

• **DNA nanocapsules** smuggle strands of viral DNA into cells. Once the capsule breaks down, the DNA hijacks the cells' machinery to produce compounds that would be expected in a virus attack, thus alerting and training the immune system to recognise them. DNA nanocapsule technology could also be used to hijack living cells to produce other compounds such as new proteins or toxins. As a result, they must be carefully monitored as a potential biowarfare technology.

Sizing Up Nano-Pharmaceuticals

Nanotechnology could offer the pharmaceutical industry the key to unleashing a torrent of new and old drug compounds. Not only are profits and patents to be gained by shrinking existing drugs to the nano-scale, but there is also the opportunity to resurrect drugs that previously failed clinical trials in a larger form. By encapsulating pharmacologically active compounds and claiming that they will be targeted to a very specific site in the body, companies could argue that general side-effects are no longer a concern, and that old safety assessments are no longer relevant.

Nano-scale pharmaceuticals approved for animal use must also be carefully tested and monitored to prevent them from entering the food chain. It is not understood how nanoparticles persist in and move around the body, nor whether they can migrate to milk, eggs and meat. Existing animal pharma drugs will need to be re-evaluated by regulatory authorities if they are re-formulated in a nano-scale form since the properties of materials can change at this size.

Sizing Up the "Nanomal" Farm

Implanting tracking devices in animals is nothing new—either in pets, valuable farm animals or for wildlife conservation. Injectable microchips are already used in a variety of ways with the aim of improving animal welfare and safety—to study animal behaviour in the wild, to track meat products back to their source or to reunite strays with their human guardians.

In the nanotech era, however, retrofitting farm animals with sensors, drug chips and nanocapsules will further extend the vision of animals as industrial production units. Animals also are likely to be used as the testing ground for less savoury or more risky applications that could later be extended to human beings.

Using microfluidics for breeding is likely to accelerate genetic uniformity within livestock species and also opens the

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possibility of applying new nano-eugenic technologies to humans in the future.

The ability to remotely regulate animals may have adverse affects as livestock go longer periods without direct human care.

The same technologies transferred to humans raise profound concerns about quality of life and civil liberties. In October 2004 the US Food and Drug Administration approved the use of implantable microchips in humans to provide easy access to an individual's medical records—the first approval of microchips for medical uses in the United States.[129]

As healthcare is driven more and more by the bottom line, the future use of implantable chips for automated drug delivery may become economically preferable to nursing.

When dealing with the elderly or those with different cognitive abilities or with any condition requiring regular treatment, ethical questions may arise about who decides to make an individual 'fuel injected.'

Automated drug delivery could allow some people to live independently who would otherwise be institutionalised. However, the absence of human caretakers is also a factor.

The Future of Farming: Nanobiotech and Synthetic Biology

At the dawn of the 21st century, genetic engineering is suddenly old hat. The world's first synthetic biology conference convened in June 2004. Two months later, the University of California at Berkeley announced the establishment of the first synthetic biology department in the United States.[136]

According to science reporter W. Wayt Gibbs, synthetic biology involves "designing and building living systems that behave in predictable ways, that use interchangeable parts, and in some cases that operate with an expanded genetic code, which allows them to do things that no natural organism can".[137] One of the goals, writes Gibbs, is to "stretch the boundaries of life and of machines until the two overlap to yield truly programmable organisms".[138]

Although synthetic biology is not always synonymous with nanobiotechnology (i.e., the merging of the living and nonliving realms at the nano-scale to make hybrid materials and organisms), the programming and functioning of "living machines" in the future will frequently involve the integration of biological and non-biological parts at the nano-scale.

Part Two looks at nanotechnology in food.

Footnotes:

Due to a lack of space we have not published the relevant and extensive footnotes. Instead, we encourage readers to obtain a copy of the full report and use it to generate debate within the community.

Editor's Note:

ETC Group is an action group on erosion, technology and concentration. Publications, including *Down on the Farm*, can be downloaded free of charge from the website: www.etcgroup.org or is available in hardcopy from:

ETC Group,
431 Gilmour St, Second Floor,
Ottawa, ON, Canada K2P 0R5.
Tel: +1 613-241-2267;
fax: +1 613-241-2506;
email etc@etcgroup.org